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A CURRENT VISION

NOAA satellite weather stations: state of the art, perspective and future projection

Estaciones satelitales meteorológicas NOAA: Estado del arte, perspectiva y proyección futura

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ABSTRACT

This document presents a documentary review of the impact done by ground satellite stations linked to NOAA's meteorological satellites, highlighting the implementation of software defined radio and some possible applications that could be given to satellite stations in terms of data and information processing. This work is done in order to find the main characteristics of these satellite communications systems and several applications, which are oriented towards the monitoring of natural phenomena for documentation and prevention; presenting the projection with the implementation is in Cloud and research through years.

RESUMEN

En este documento se realiza una revisión documental del impacto de la implementación de estaciones satelitales terrestres enlazadas a los satélites meteorológicos de la entidad NOAA resaltando la implementación de radio definido por software y las posibles aplicaciones que se le podrían das a las estaciones satélites en cuanto al procesamiento de datos e información; este trabajo es realizado con el fin de hallar las principales características del estos sistemas de comunicaciones satelitales y las diferentes aplicaciones, las cuales esta orientadas hacia el control y monitoreo de fenómenos naturales para documentación y prevención de estos; presentando la proyección con la implementación en Cloud y las investigaciones en los años.

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1. Introduction

There are plenty of natural phenomena that cause a weather(/climate) impact and lead to alerts and affectations in different social and economic sectors of different countries. For example: between April 25 and 28 of 2011, the first wave of tornadoes occurred in the United States that would lead to catastrophic damage in the south and east of the country, with this problem the strategic plan "Building a Weather-ready Nation" by the NWS (National Weather Service) arises. Where decision makers community have access to information that is understandable and prepares them to take action to safeguard lives and means of subsistence before the occurrence of dangerous conditions, using the latest advances in science and technology, modeling, social sciences, and information delivery systems.

The NWS in cooperation with NOAA (National Oceanic and Atmospheric Administration) will operate as a prevention enhancer that raises the level of preparedness for disasters [1], this will be done through the acquisition and analysis of meteorological information; thus, in this way to be able to preserve the lives of people through the development of data collection, recommendations for risk prevention and different research. The NOAA entity has distinguished itself for having at its disposal different fields of research, mainly focused in keeping the public advised of a changing environment, through daily weather forecasts, severe storm warnings, climate monitoring, fisheries management, coastal restoration, and support to marine commerce [2-8].

The benefits of obtaining meteorological information are: 1) Quantification and estimation of services, that is, when companies, people and / or government entities control to reduce costs based on the availability of the information, 2) Natural phenomena preparation and 3) Commercial decisions [9-10].

Considering the impacts that natural phenomena have, and the benefits that can be reached from them through obtaining meteorological information. This paper presents a documentary review where the perspective of the NOAA and its applications in the development of meteorological information, clarifying that this review is aimed to be a tool to get a vision of how NOAA's research is oriented and its different academic and case study applications. This paper is divided into five sections: 1) NOAA satellite classification, 2) implementation of satellite ground stations through SDR, 3) Weather information applications, 4) weather analysis in Colombia, and Projection and 5) conclusions.

2. Theorical background NOAA satellites

From the different development fields at NOAA, satellites are considered one of the most open fields for research operated by NESDIS (National Environmental Satellite, Data, and Information Service), they are responsible for providing secure and timely access to global environmental data and information from satellites and other sources, to promote and protect environmental security. The meteorological information provided by this entity comes from the constellation of POES (Polar Operational Environmental Satellite) and GOES (Geostationary Operational Environmental Satellite) satellites mainly, these satellites fly in the orbits which are synchronized with the sun, that is, they will always orbit in the same position and exactly at the same time which allows them to obtain a global vision of the earth [11]. Table 1 summarizes the satellites deployed by NOAA and which are intended for the transmission of climate data in two orbits, the polar and the geostationary.

Table 1. NOAA satellite status description [12-15].

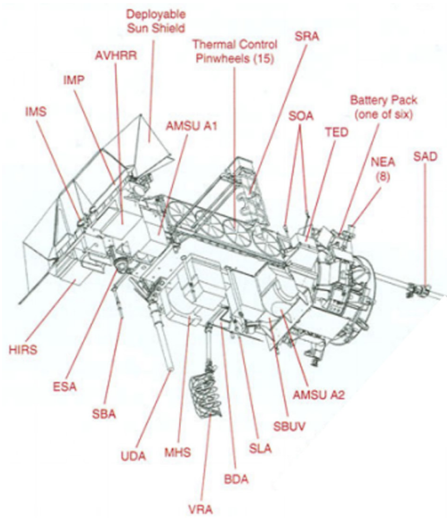
Satellite	Orbit	Operation Status
GOES-8 a 12	GEO	Off
GOES-14	GEO	Off
GOES-15	GEO	On orbit
GOES-16	GEO	On orbit
GOES-17	GEO	On orbit
NOAA-11, 12, 14, 16, 17	Polar	Off
NOAA-15	Polar	On orbit
NOAA-18	Polar	On orbit
NOAA-19	Polar	On orbit
NOAA-20	Polar	On orbit
Suomi NPP	Polar	On orbit

Source: own.

The transmission of satellite images is exposed to factors such as noise that affect image quality, for the correction in the transmission of these images, comparison between the satellites is made to determine which one is more optimal for this purpose. In [16-17] an algorithm was developed to mitigate the stripping noise that is common in geospatial remote censoring of images on ATMS (advanced microwave technology probes) channels and the comparison between NOAA-20 and S-NPP satellites, with respect to the RO (Radio occultation) parameter; the developed algorithm allowed to reduce the noise levels finding that in the NOAA-20 satellite in the ATMS channels it has a higher trend in magnitude allowing to have a higher symmetry in its different channels (frequency bands). In [18] they perform the improvement of the VIIRS sensor (Visible Infrared Imaging Radiometer Suite) to improve the geolocation before and after the processing where the correction and calibration of the geometric parameters are incorporated. These developments were an important step as the data obtained from numerical climate predictions allow effective use of the data for climatological studies.

Each GOES or POES has type of sensors and components as shown in Figure 1. This information provided by these elements is transmitted through the different bands of each of the satellites, each band shows different weather parameters such as water vapor, ozone, CO2, cloud particles, snow / ice, GeoColor, among others [19-20].

Figure 1. Instruments and components of the POES satellites [21].



AMSU	Advanced Microwave Sounding Unit
AVHRR	Advanced Very High Resolution Radiometer
BDA	Beacon Dipole Antenna
ESA	Earth Sensor Assembly
HIRS	High Resolution Infrared Radiation Sounder
IMP	Instrument Mounting Platform
IMS	Inertial Measurement System
MHS	Microwave Humidity Sounder
NEA	Nitrogen Engine Assembly
SAD	Solar Array Drive
SBA	S-Band Antenna
SBUV	Solar Backscatter Ultraviolet Radiometer
SLA	Search and Rescue Transmitting Antenna (L-Band)
SOA	S-Band Omni Antenna (2 of 6 shown)
SRA	Search-and-Rescue Receiving Antenna
TED	Total Energy Detector
UDA	Ultra High Frequency Data Collection System Antenna
VRA	Very High Frequency Real-time Antenna

Source: own.

This satellite information presents the opportunity to make low-cost satellite stations given the accessibility of the information. Below, the different applications that have been given to it and what elements it needs for its operation, will be exposed.

2.1. Satellite Ground stations

The satellite ground stations have the capacity to process the information of the signals sent from the satellites; these have active devices like amplifiers, and passive devices like reflectors or filters. The different types of SDR (Software Defined Radio) devices are capable of receiving radio frequency signals, converting them into baseband, digitizing them and sending them through interfaces such as USB, thus, allowing an optimization in hardware between the antennas and the computer system for the construction of satellite ground stations, to observe the possible applications of this system in the reception of meteorological images.

Software Defined Radio refers to radio systems in which almost all the functionality associated with the physical layer is implemented in software that uses PSD (Digital Signal Processing) algorithms [22]. The most representative software platforms are GNU radio, LabVIEW and Matlab. To perform the processing of the NOAA satellite files, a device compatible with the SDR platform must be connected, chosen as in [23-29] which makes use of the devices shown in table 2.

Table 2. Signal transceiver devices. [23-25], [30–32].

Hardware	Bandwidth	Sample Frequency
Icom PCR-1500	10 kHz - 3,3GHz	< 5MHz
USRP 2920	50 MHz - 2,2GHz	20 MHz – 40 MHz
RTL-SDR 2832U	500 kHz - 1,766GHZ	500 kHz – 24MHz

Source: own.

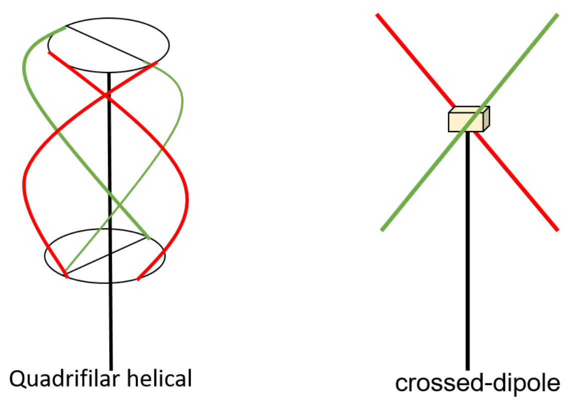
These devices perform the function of making the connection between the receiving antenna and a computer. With the computer setup, the digital processing of baseband radio signals and image processing is done by block programming as in [23], [25], [29], [33], which consists of three stages; the first one is the filtering and resampling, followed by decoding and demodulation, and finally the displaying and storing of images.

2.2. Antennas

NOAA satellites in a frequency range from 137.5 MHz to 137.9 MHz perform APT (Automatic Image Transmission) in AM or FM modulation with signals circularly polarized to the right [21]. The antenna and the circular polarization are fundamental when receiving the signal and better image quality, since a good antenna allows to capture the necessary amount of signal so that the images have a better resolution according to their receiving antenna. Therefore, different antenna array designs have been developed such as: crossed-dipole, quadrifilar helical and parabolic antennas. These antennas have two characteristics: 1) they are adapted to receive circularly polarized signals on the right and 2) they have an omnidirectional radiation pattern, see Figure 2.

In [34]-[36], they are focused on the development of weather satellite image receiving antennas from NOAA's satellites, where the performance of each is measured from values such as R.L (Return Loss), VSWR (Standing Wave Ratio), gain and impedance; considering that there are optimal values for antenna arrays as shown in Table 3 [36].

Figure 2. Schematic of receiving antennas for NOAA satellites.



Source: own.

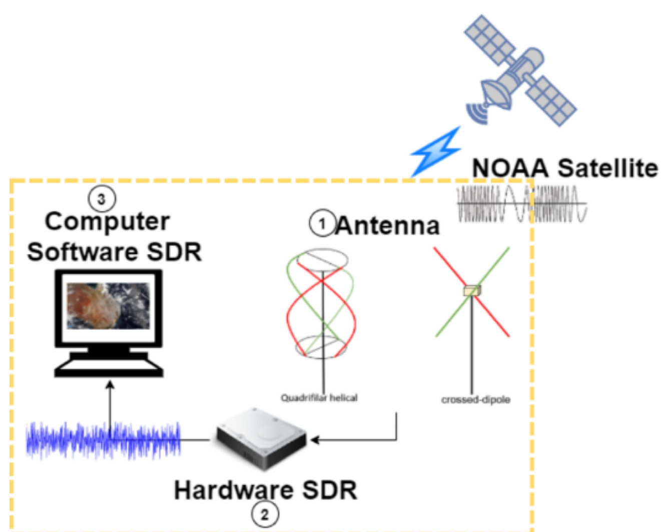
Considering the implementation of the antennas, the SDR hardware and software, together lead to low-cost satellite ground stations. In [37], [38] a cost reduction of 50% to 55% in infrastructure, needed for implementation and a greater flexibility for image processing, was reported; and since polar-orbiting satellites such as NOAA -15, -18 and -19 are in constant transmission, there will be no need to wait for a specific data acquisition. The cost reduction and optimization of these satellite stations is mostly due to the use of SDR tools for information processing. As mentioned in section 2.1, in [22], elements such as elements like physical filters were switched to programmable digital filters with the different GNU tools. Satellite ground stations can be summarized in three stages 1) reception, 2) coupling and 3) image processing, as shown in figure 3.

Table 3. Reference values in the receiving antennas of NOAA satellites according to [36].

Parameters	**NOAA values**
Frequency	137,5 MHz - 137,9 MHz
Return Loss	< -10 dB
VSWR	< 2
Gain	> 3 dB
Radiation pattern	omnidirectional

Source: own.

Figure 3. Low-cost satellite ground station implemented SDR.



Source: own.

3. Satellite Ground Station Applications

The implementation of low-cost and portable satellite stations increases the coverage to obtain information. Different studies have been carried out where the advantages of these stations can be observed. In [39], they present some case studies where the main goal was to classify estuaries and cyclones. Estuaries are the most difficult marine environments to classify due to the great space-time variability that gives rise to benthic conditions. In [40] by training of a neuronal network loaded with information of the Gonu cyclone, was determined a relation between the temperature brightness and the cyclone nucleus found patterns of behavior for the prevention of future cyclones. Also, automatic alerts from volcanic cloud detection sensors were evaluated in [41] as a function of thermal emissions. This study was performed with infrared thermal information from GOES-15 and Himawari-18 satellites and the VIIRS sensor.

There are other applications that are not based on variables or monitoring, but strategies have also been developed for remote sensing of forest fires based on CO2 concentrations via convolutional neural networks [42]. The prediction of ozone columns by regression algorithms [43] or the use of beamforming algorithms for tracking LEO satellites with adaptive antenna arrays [44]. Figure 4 summarizes the applications that make use of NOAA's information, which are classified into four (4) groups: 1) monitoring and control of climate variables as in [16], [17], [41], [45], [46], 2) case studies for the analysis of specific environments or natural phenomena as in [39], [40], 3) neural networks [40], [42], [43], [47] and 4) risk prevention of natural phenomena [42], [47].

The research documented in section 2 and 3 are three (3) main points, in the research they show the course and importance of each one of them. Separately, all of them are being oriented towards the study of climate and natural phenomena by meteorological data; this can be evidenced in table 4.

Table 4. Main objectives of the research done with meteorological information [24], [27], [42].

NOAA meteorological data applications		
Study cases	**Satellite stations**	**Data processing**
These are oriented to the analysis of specific phenomena, from which behavioral information is being obtained to characterize environments, impact of natural phenomena and monitoring of conditions where public and private sectors are being affected	These researches now are focusing on the development of receiving systems for climatic and meteorological signals from NOAA's satellites, where the use of Software Defined Radio hardware and software can be highlighted to reduce costs in the digital processing of information and the design of receiving antennas in the elaboration of terrestrial satellite stations.	There are different methods for the processing of climate information from NOAA's satellites. From the research, the use of algorithms and automatic learning methods such as convolutional neural networks are highlighted, which mostly seek to perform the prediction of the behavior of different natural phenomena.

Source: own.

3.1. Meteorological analysis in Colombia

In Colombia there is an public entity called IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales), in 2013, in conjunction with NOAA, held a seminar about tropical cyclones and their impact on different socio-economic aspects; IDEAM was also chosen in 2017 by the WMO (World Meteorological Organization) [48] as a pioneer for the implementation of the GFSC (Global Framework for Climate Services), so they can offer to all the productive sectors of the country better hydrometeorological information. IDEAM has developed an interface that allows the analysis and visualization of the country's meteorological status using the GOES-16 satellite with its 16 channels of meteorological information [49], while reporting accidents such as landslides and fires.

In table 5, the common factors present between IDEAM and NOAA are analyzed, thus finding similar approaches between: preservation of different ecosystems, risk prevention and the way information is presented.

Table 5. Feature comparison between NOAA and IDEAM [50-51].

	NOAA	IDEAM
Weather	Compiles the US climate information provided by news, maps, and images.	Consults the climatological characteristics of the different regions of the national territory.
Oceans and Coasts	Provides data, tools and services that support coastal economies and their contribution to the national economy.	Perform national studies of hydrology in rivers and basins; hydrological risk and evaluation
Environments	Focused on the management and conservation of national marine sanctuaries, protection of marine areas and estuaries to enable local economic benefit	Presents the information of the research processes in coastal and marine continental ecosystems, the ecological structure, the dynamics of the layers, the monitoring and follow-up of the quality of soils and lands.

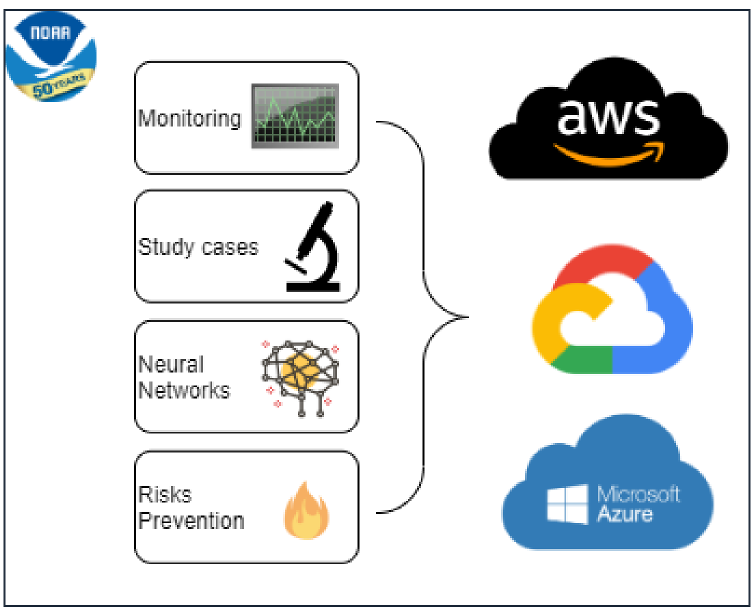
Source: own.

In Colombia, research has been done as in [52], where the comparison of two software tools for the coordination of the ROE (Recurso Orbita Espectro) in the geostationary orbit was performed, with the software Visualyse OSG and Sat-Coord, the behavior of variables such as the C/N (noise carrier ratio), C/I (interference carrier ratio), among others, was compared. From the results obtained, the precision of the Visualyse OSG tool and its capacity of handling calculations, stand out; however, none of these tools allows the analysis in planning bands. The research highlights the usefulness that has been for the ANE (Agencia Nacional del Espectro) in the studies and planning of frequencies for geostationary orbit satellite networks.

4. Future planning

The large amount of data generated by this type of systems means that new media or platforms are being used to process and store meteorological data and, to continue with these applications, the use of Cloud Computing is being oriented. With the NOAA project "NOAA Big Data Project", collaborations with AWS (Amazon Web Services), Google Cloud and Microsoft have been announced; in which they seek to combine NOAA's meteorological information, the growing infrastructure of Cloud companies and the information processing capacity.

Figure 4. Applications of NOAA information [53-55].



Source: own.

5. Conclusions

From the documental analysis of the different articles that make developments based on the meteorological information of the NOAA satellites, finding the importance of keeping the record, monitoring and surveillance of the environment, based on the information of different variables for the categorization of natural phenomena; allowing different entities to create mitigation plans to take decisions that will affect public and private sectors.

The open access to this meteorological information has enabled different fields of research such as the vectorization of climate behavior, the implementation of remote sensing of natural phenomena with neural networks and with Artificial Intelligence for recognition and prediction of weather patterns.

The use of SDR in the development of satellite ground stations showed two (2) considerable advantages, firstly the reduction of hardware costs, as several processes such as signal filtering can be implemented by programmable blocks in a virtual and not physical layer; secondly, the mobility and flexibility of satellite stations considering that it reduces the difficulty of movement and allows scalability in the acquisition of results.

The implementation of infrastructure as a service for processing, storing and obtaining meteorological information from NOAA in association of AWS, Google Cloud and Microsoft allows the growth and strengthening of meteorological analysis seeing that it allows the implementation of new tools such as devops or serverless in meteorological analysis, where it would be possible to use infrastructure that can grow vertically and/or horizontally, with resilience and that is designed for failures.

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